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ELECTRIC WAVE MULTIPLIER CIRCUIT

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*Fig. 1.*

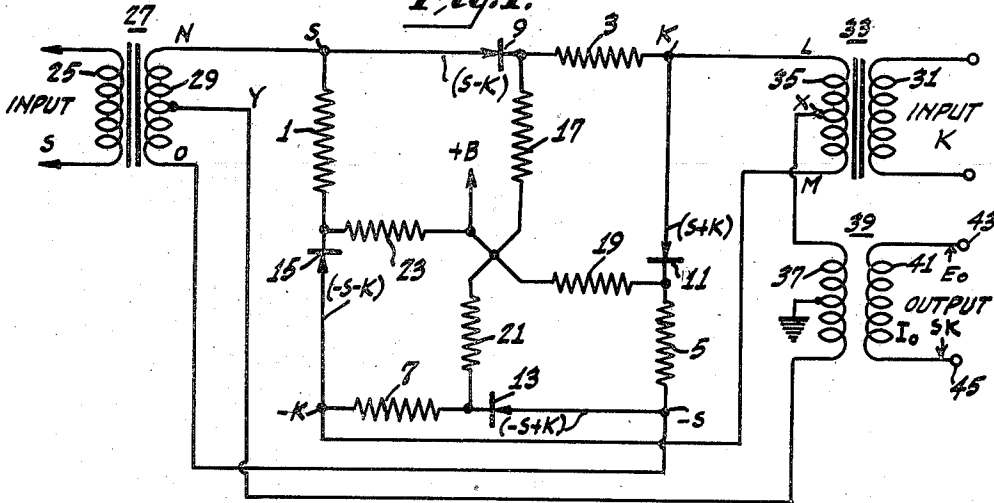
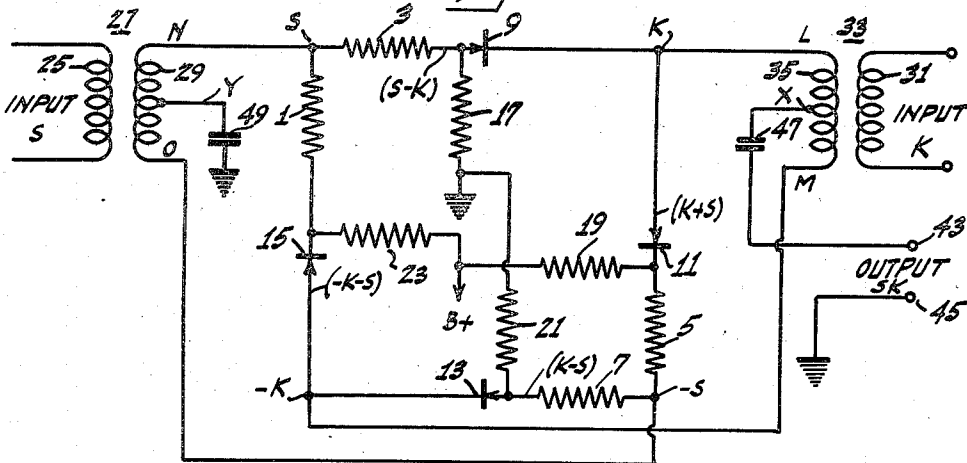


*Fig. 2.*



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## UNITED STATES PATENT OFFICE

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## ELECTRIC WAVE MULTIPLIER CIRCUIT

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16 Claims. (Cl. 179—1.5)

The present invention relates generally to the multiplication of voltages and more particularly to improved methods of and means for deriving the product of two signals for use, for example, in secret telecommunication systems.

It should be understood that the invention may be employed wherever it is desired to obtain a signal having instantaneous wave form ordinates which are the product of the corresponding instantaneous ordinates of two component signals. A particular application of the invention is in secret telecommunication systems of the type described in the copending application of Alda V. Bedford Serial No. 536,630 filed May 20, 1944. Said copending application discloses a system wherein, for example, a speech signal comprising a complex wave S is multiplied by a coding signal comprising a second complex wave K whereby the instantaneous ordinates of the resulting coded signals are the product SK of the corresponding instantaneous ordinates of the speech signal and the coding signal. The resulting unintelligible coding signals are transmitted by any conventional means to a receiver wherein the coded signals are multiplied by decoding signals, locally generated in the receiver, which have instantaneous ordinates corresponding to the reciprocals of the corresponding instantaneous ordinates of the original coding signal component K of the transmitted signal. The final decoded signals, therefore, are derived from the product of the transmitted signal SK and the decoding signal

$$\frac{1}{K}$$

The coding and decoding signal generators are synchronized by means of special synchronizing pulse signals transmitted with the coded wave.

The instant invention comprises an improvement over a signal multiplier circuit described and claimed in another copending application of Alda V. Bedford Serial No. 517,967 filed January 12, 1944. In said latter copending application, a bridge network comprising eight serially-connected resistors includes four "square-law" copper-oxide rectifying devices connected to intermediate points on said bridge and having a common output connection. Signals from two component wave sources are applied to different diagonally opposite points on the resistive bridge.

Signals derived from the common terminal of the rectifying devices have ordinates which are proportional to the product of the ordinates of the component signals applied to the bridge.

The present invention has several advantages over said prior art multiplying circuit. For example, the bridge network of the instant invention comprises only four serially-connected resistors having the four "square-law" rectifying devices serially interposed therebetween. The component signals may be applied to the bridge network through separate transformers having their secondary windings connected to different diagonal points on the bridge. The output product signal may be derived through another transformer, or other output network, connected between the secondary windings of the component signal input transformers. The instant improved multiplier circuits have the additional advantage of increased efficiency in that the input signals are not shunted by the voltage dividing resistors of the bridge network as is the case in said prior art device. Also, the present invention permits the use of great latitude in input and output impedance values for predetermined bridge parameters, whereas the prior art device is less flexible in these respects.

Among the objects of the invention are to provide an improved method of and means for multiplying two signal voltages by each other to derive a product signal. Another object of the invention is to provide an improved multiplying circuit employing "square-law" signal rectifying devices having the property of providing an instantaneous output current which is proportional to the square of the applied instantaneous voltage for reasonable swing in a single polarity. A further object of the invention is to provide an improved circuit for obtaining the product of two electrical signals wherein none of the original component signals appear in the output signal. Another object of the invention is to provide an improved signal multiplier for use in secret telecommunication systems. An additional object is to provide an improved signal multiplying circuit having high efficiency. Another object is to provide an improved signal multiplying circuit permitting wide latitude in input and output impedance values for predetermined circuit parameters.

The invention will be described in greater de-

tail by reference to the accompanying drawing of which Figure 1 is a schematic circuit diagram of one embodiment thereof, and Figure 2 is a schematic circuit diagram of a second embodiment of the invention. Similar reference characters are applied to similar elements throughout the drawing.

Referring to Figure 1, a typical embodiment of the signal multiplier comprises a resistive bridge including four 8000 ohm bridge resistors 1, 3, 5, 7, serially connected with four "square-law" signal rectifiers 9, 11, 13 and 15 to provide a closed series circuit having one rectifier interposed between each of the bridge resistors, said rectifiers being connected in series-aiding polarity. The positive terminal of a source of bias potential, not shown, is connected to the common terminals of four 2 megohm bias resistors 17, 19, 21, 23. The negative terminal of the bias voltage source may be grounded. The remaining terminals of each of the bias resistors are connected to the anode terminals of different ones of the signal rectifiers. It should be understood that the "square-law" signal rectifiers may be of the commercial copper-oxide types known as "Varistors" or "Rector," wherein an applied voltage of one predetermined polarity provides an output current having values proportional to the square of the applied voltage over a predetermined voltage range.

Input signals from a first signal source S, not shown, are applied to the primary winding 25 of a first input transformer 27. The transformer 27 includes a center-tapped secondary winding 29 of which the end terminals N and O are connected respectively to the voltage points S and -S on the bridge network. Similarly, a second input signal source K, not shown, is connected to the primary winding 31 of a second input transformer 33. The second transformer 33 includes a center-tapped secondary winding 35 having end terminals L and M which are connected, respectively, to the voltage points K and -K on the bridge network.

Therefore, the total voltage at the point S will be (S-K); the total voltage at the point K will be (S+K); the total voltage at the point -S will be (K-S) and the total voltage at the point -K will be (-S-K). The bias voltage source should be sufficiently high to provide a bias voltage on each of the signal rectifiers sufficient to prevent any reversal in signal voltage polarity and to insure "square-law" operation over the applied signal voltage range.

The center terminal X of the secondary winding 35 of the second input transformer 33 is connected to one terminal of the center-tapped primary winding 37 of an output transformer 39. Similarly, the center terminal Y of the secondary winding 29 of the first input transformer 27 is connected to the remaining end terminal of the center-tapped primary winding 37 of the output transformer 39. The output transformer primary winding center tap is grounded. The secondary winding 41 of the output transformer 49 is connected to the output terminals 43, 45.

In operation, it will be understood that the output voltage  $E_o$  across the terminals 43, 45 will be proportional to the output current  $I_o$  through the transformer secondary winding 41. Also, the output current  $I_o$  will be proportional to the difference of the currents  $I_x$  and  $I_y$  derived from the center terminals of the input transformers 33 and 27, respectively. The current  $I_x$  is seen

to be equal to the sum of the currents in the leads L and M connected to the end terminals of the primary winding 35 of the second transformer 33. Similarly, the current  $I_y$  is equal to the sum of the currents in the connections to the terminals N and O of the secondary winding 29 of the first input transformer 27. Since

- (1)  $E_o \propto I_o$
- (2)  $I_o \propto I_x - I_y$
- (3)  $I_x = I_L + I_M$
- (4)  $I_y = I_N + I_O$

and, the term A representing the fixed current due to the applied bias potential,

- (5)  $I_L \propto (S+K+A)^2$
- (6)  $I_M \propto (-S-K+A)^2$
- (7)  $I_N \propto (S-K+A)^2$
- (8)  $I_O \propto (-S+K+A)^2$

Therefore,

$$(9) E_o \propto (S+K+A)^2 + (-S-K+A)^2 - [(S-K+A)^2 + (-S+K+A)^2]$$

which, expanded, provides

$$(10) E_o \propto (S^2 + K^2 + A^2 + 2AS + 2AK + 2SK) + (S^2 + K^2 + A^2 - 2AS - 2AK + 2SK) - [(S^2 + K^2 + A^2 + 2AS - 2AK - 2SK) + (S^2 + K^2 + A^2 - 2AS + 2AK - 2SK)]$$

which, being simplified, results in

$$(11) E_o \propto 2S^2 + 2K^2 + 2A^2 + 4SK - [2S^2 + 2K^2 + 2A^2 - 4SK]$$

whereby

$$(12) E_o \propto 8SK \approx SK$$

Thus, it is seen that the output voltage  $E_o$  derived from the output terminals 43, 45 is proportional to the product SK of the input signals S and K applied to the primary windings of the input transformers 27 and 33.

The circuit of Figure 2 is similar in many respects to the circuit of Figure 1 described heretofore, with the exception that it is adapted to utilize conventional double rectifier units wherein the anode of one rectifier is connected mechanically to the cathode of the other rectifier. Since commercial embodiments of these devices do not permit the insertion of circuit elements in this common connection, the circuit of Figure 2 has been devised to overcome this difficulty. Essentially, the principal change in the bridge network of the circuit of Figure 2 with respect to the corresponding bridge network of the circuit of Figure 1 is that the relative positions of the signal rectifiers 9, 11, 13, 15 have been changed with respect to the serially-connected bridge resistors 1, 3, 5 and 7. The changed connections require that the positive terminal of the bias voltage source be connected through the bias resistors 19 and 23 to the anodes, respectively, of the signal rectifiers 11 and 15, while the cathodes of the signal rectifiers 9 and 13 are connected, respectively, through the bias resistors 17 and 21 to the grounded negative terminal of the bias voltage source.

The end terminals N, O of the secondary winding 29 of the first input transformer 27 are connected to the voltage points S and -S, respectively, on the bridge network. The point S corresponds to the common connection of the bridge resistors 1 and 3, while the voltage point -S corresponds to the common connection of the bridge resistors 5 and 7. The end terminals L and M of the secondary winding 35 of the second input

transformer 33 are connected, respectively, to the voltage points K and  $-K$ , which correspond to the common terminals of the rectifiers 9, 11 and 13, 15, respectively. The resultant signal voltage distribution at each of the rectifier units is indicated on the drawing in the same manner as in the circuit of Figure 1.

The output voltage SK is derived from the output terminals 43, 45. The output terminal 43 is connected through a first coupling capacitor 47 to the center tap X of the secondary winding 35 of the second input transformer 33. Similarly, the grounded output terminal 45 is connected through a second coupling capacitor 49 to the center terminal Y of the secondary winding 29 of the first input transformer 27. It should be understood that the output transformer connection or output capacitor connection thus described may be interchanged in the two circuits of Figures 1 and 2.

The operation of the circuit of Figure 2 is substantially identical to the operation described heretofore for the circuit of Figure 1, although it should be understood that the effect of the coupling capacitors 47, 49 in the output network of the circuit of Figure 2 must be taken into consideration if the frequency range of the applied signals is relatively wide.

Thus the invention described comprises improved signal multiplying circuits of the type which provide an output signal having instantaneous ordinates which are proportional to the product of the instantaneous ordinates of two applied signals. The circuits described require less circuit components and provide greater operational stability and efficiency than the similar devices described in the copending applications mentioned heretofore.

I claim as my invention:

1. The method of obtaining the product of two electrical signals of varying amplitudes which comprises deriving four different polarity combinations of said signals, squaring each of said combinations, adding two of said squared combinations to derive a first sum signal, adding the remaining two of said squared combinations to derive a second sum signal and subtracting said first and second sum signals to derive said product of said signals.

2. The method of obtaining the product of two electrical signals of varying amplitudes which comprises deriving in combination with a constant amplitude voltage four different polarity combinations of said signals, squaring each of said combinations, adding two of said squared combinations to derive a first sum signal, adding the remaining two of said squared combinations to derive a second sum signal and subtracting said first and second sum signals to derive said product of said signals.

3. Apparatus for obtaining the product of two electrical signals of varying amplitudes including means for deriving four different polarity combinations of said signals, means for squaring each of said signal combinations, means for adding two of said squared combinations to derive a first sum signal, means for adding the remaining two of said squared combinations to derive a second sum signal, and means for subtracting said first and said second sum signals to derive said product of said signals.

4. Apparatus for obtaining the product of two electrical signals of varying amplitudes including means for deriving in combination with a constant amplitude voltage four different polarity

combinations of said signals, means for squaring each of said signal combinations, means for adding two of said squared combinations to derive a first sum signal, means for adding the remaining two of said squared combinations to derive a second sum signal, and means for subtracting said first and said second sum signals to derive said product of said signals.

5. Apparatus for obtaining the product of two electrical signals of varying amplitudes including means for combining said signals in four different polarity combinations, separate non-linear devices for squaring each of said signal combinations, first means for adding the squared signals derived from two predetermined ones of said devices, second means for adding the squared signals derived from the others of said devices, and means for combining in phase opposition said added squared signals derived from said first and said second adding means to derive said product of said signals.

6. The method of obtaining the product of two electrical signals S and K of varying amplitudes which comprises the steps of combining said signals in the polarity combinations  $(S+K)$ ,  $(-S-K)$ ,  $(S-K)$  and  $(K-S)$ , squaring each of said combinations, adding said squared combinations  $(S+K)^2$  and  $(-S-K)^2$ , adding said other squared combinations  $(S-K)^2$  and  $(K-S)^2$ , and subtracting said other added squared combinations from said first mentioned added squared combinations to derive said product SK.

7. Apparatus for obtaining the product of two electrical signals S and K of varying amplitudes including means for combining said signals in the polarity combinations  $(S+K)$ ,  $(-S-K)$ ,  $(S-K)$ , and  $(K-S)$ , means for squaring each of said combination signals, means for adding said squared combinations  $(S+K)^2$  and  $(-S-K)^2$ , means for adding said other squared combinations  $(S-K)^2$  and  $(K-S)^2$ , and means for subtracting said other added squared combinations from said first mentioned added squared combinations to derive said product SK.

8. The method of obtaining the product of two electrical signals S and K of varying amplitudes which comprises the steps of combining said signals with a constant amplitude voltage A in the polarity combinations  $(S+K+A)$ ,  $(-S-K+A)$ ,  $(S-K+A)$  and  $(K-S+A)$ , squaring each of said combinations, adding said squared combinations  $(S+K+A)^2$  and  $(-S-K+A)^2$ , adding said other squared combinations  $(S-K+A)^2$  and  $(K-S+A)^2$  and subtracting said other added squared combinations from said first mentioned added squared combinations to derive said product SK.

9. Apparatus for obtaining the product of two electrical signals S and K of varying amplitudes including means for combining said signals with a constant amplitude voltage A in the polarity combinations  $(S+K+A)$ ,  $(-S-K+A)$ ,  $(S-K+A)$  and  $(K-S+A)$ , means for squaring each of said signal combinations, means for adding said squared combinations  $(S+K+A)^2$  and  $(-S-K+A)^2$ , means for adding said other squared combinations  $(S-K+A)^2$  and  $(K-S+A)^2$  and means for subtracting said other added squared combinations from said first mentioned added squared combinations to derive said product SK.

10. Apparatus for obtaining the product of two electrical signals of varying amplitudes including resistive bridge means for combining said signals in four different polarity combinations, separate

non-linear rectifier devices serially connected with said resistive bridge means for squaring each of said signal combinations, first transformer means connected to said bridge means for adding the squared signals derived from two predetermined ones of said rectifier devices, second transformer means connected to said bridge means for adding the squared signals derived from the others of said rectifier devices, and means for combining in phase opposition said added squared signals derived from said first and said second adding means to derive said product of said signals.

11. Apparatus for obtaining the product of two electrical signals of varying amplitudes including resistive bridge means for combining said signals in four different polarity combinations, separate non-linear rectifier devices serially connected with said resistive bridge means for squaring each of said signal combinations, a source of bias potential, relatively high resistive means for applying said bias potential to each of said rectifier means for operating said rectifier means as square law devices, first transformer means connected to said bridge means for adding the squared signals derived from two predetermined ones of said rectifier devices, second transformer means connected to said bridge means for adding the squared signals derived from the others of said rectifier devices, and means for combining in phase opposition said added squared signals de-

rived from said first and said second adding means to derive said product of said signals.

12. Apparatus of the type described in claim 11 characterized in that said electrical signals are applied to said bridge means through said first and said second transformers.

13. Apparatus of the type described in claim 11 including an output transformer coupled between said first and said second transformers for deriving said product signal.

14. Apparatus of the type described in claim 11 characterized in that at least two of said rectifier units have common electrical terminals.

15. Apparatus of the type described in claim 11 including means for isolating said bias voltage from said derived product signals.

16. Apparatus for obtaining the product of two signals comprising a ring modulator including four non-linear rectifying devices arranged in the form of a closed bridge, means serially interposed with each of said devices to adjust the operational characteristics of each of said devices to provide "square law" operation over a predetermined portion of the operating range of said devices, fixed bias voltage means connected to each of said devices for operating said devices in said square law operational range, and means for applying said signals to said modulator.

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